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Topographic Engineering Center
U.S. Army Engineer Research and Development Center
7701 Telegraph Road
Alexandria, VA 22315-3864

Final report

Preface

This report was prepared under In-House Laboratory Independent Research (ILIR) Project 0060L5 "Vegetation Inferencing."

This research was conducted during the period October 1999 through July 2000 by Dr. Paul F. Krause, Harry B. Puffenberger, and Michael V. Campbell, Terrain Data Generation Branch, Topographic Research Division, Topographic Engineering Center (TEC). The work was performed under the supervision of Kevin R. Slocum, Team Leader, Terrain Data Generation Branch and William Z. Clark, Jr., Acting Chief, Topographic Research Division.

COL James A. Walter was Director and Francis G. Capece was Technical Director of TEC at the time of report publication.

TEC is an element of the U.S. Army Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. The Director of ERDC is Dr. James R. Houston and the Commander is COL James S. Weller.

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Contents

List of Figures and Tables

Figures

Tables

1 Introduction

Classical military terrain analysis typically includes an interpretation and evaluation of numerous geophysical and biophysical characteristics of the earth's surface within some specific area of interest. Geophysical parameters include surface materials (including both soils and surface geology), surface configuration (i.e., slope and aspect), surface drainage (i.e., landform class), and water resources. The primary biophysical parameter is a detailed description of the unique vegetation cover types. The interaction and spatial dependencies of adjacent or overlapping geophysical and biophysical parameters can result in highly complex terrain that potentially requires extensive reconnaissance to accurately and precisely define and delineate. Remotely sensed data sources may offer the most cost-effective method for large area terrain analysis. However, most airborne and space imagery acquired for both manual and automated (or semi-automated) feature extraction is acquired from overhead orientation. Therefore, with the sensor oriented nadir to the earth's surface, identifying and delineating physical phenomena that are subordinate to (i.e., beneath) taller and wider dominant feature classes may be highly inaccurate, if not unattainable.

Terrain analysis data base specifications list desired "overlay" information for a variety of geophysical parameters (DMA, 1982). Several critical vegetation structural and compositional variables are listed as well, including:

1. Vegetation type
2. Canopy closure percentage
3. Stem spacing
4. Vegetation height
5. Vegetation roughness factors
6. Tree stem diameter
7. Undergrowth.

Each of these vegetation characteristics is identified as an essential element of terrain information (HQDA, 1990) to be delineated onto hardcopy map overlays. Each overlay is the product of some level of detailed manual interpretation of one or more remotely sensed images. The monoscopic and stereoscopic surface feature classification relies on the interpreter's ability to accurately identify the

dominant landscape theme (e.g., forest type, shrub community, grass species association) and then to accurately infer the subordinate landscape themes (e.g., understory vegetation, soil conditions, water class).

This research effort examines the empirical relationship between the species composition and physical structure of the dominant vegetation layer and the biophysical density of the subordinate (i.e., understory) vegetation layers. Current military terrain analysis methods employ subjective procedures for estimating the nature and extent of understory vegetation strata. Tactical data base specifications used by the National Intelligence and Mapping Agency (NIMA) assign understory vegetation density estimates to only two possible classes: (1) greater than 50 percent understory density, and (2) less than 50 percent density or undetermined. These extremely broad class definitions provide only limited input to the various tactical terrain models, including: cross country mobility, cover and concealment, line-of-sight, and bivouac areas. Furthermore, the characteristic of "50 percent understory density" can be interpreted in a variety of ways and therefore does not represent a truly empirical measure of the biomass of woody and herbaceous vegetation below the dominant woody overstory. Therefore, there is a need to:

- improve on the definitions of understory and understory density relevant to tactical military terrain data base generation protocols
- enhance the analyst's ability to accurately and precisely estimate understory vegetation physical and compositional characteristics through the interpretation of the dominant overstory characteristics
- allow the data to be quickly and accurately predicted using areal photography and high-resolution multi-spectral imagery.

2 Objectives

The ability to observe, record, and quantify dominant vegetation features over large areas has been developed and refined over the past 60 years following the widespread use of both large- and small-scale aerial photography and imagery. In the last 30 years, digital technologies have been used to create vegetation type maps. However, the ability to directly observe subordinate vegetation strata remains a predictive procedure for typical passive, optical remote sensing devices. Some applications with active sensors, such as airborne radar and lidar systems, have attempted to directly quantify understory vegetation densities with marginal accuracy.

Therefore, the purpose of this project is to begin to develop some preliminary predictive relationships between forest overstory characteristics and forest understory densities. The specific objectives include:

- to develop a field sampling strategy that ensures accurate and precise quantification of both forest overstory and woody understory species composition and vertical structure
- to develop predictive relationships using forest overstory parameters as the independent variables and woody understory stem density as the dependent variable.

3 Background

The study of the relative quantities of vegetation biomass within multi-layered or multi-storied forest types has been applied to a wide variety of ecological areas. Examples of studies that have investigated the differences in the horizontal distributions of the vertically arranged composition and structure of multi-layered forest canopies, include:

- wildlife habitat evaluations
- forest successional research
- vertical species diversity studies (especially in tropical and neotropical regions).

The characteristics that define each individual layer in a multi-tiered forest canopy differ drastically from one forest type to another. Past site disturbances, whether natural (e.g., fire, flood, storm event) or anthropogenic (land clearing, controlled burn, pollution impacts) likely play the greatest role in determining the current forest stand dynamic conditions. After the impacts from disturbance, local and regional landscape characteristics typically control the number of species within a specific forest type and their vertical placement in the perennial vegetated canopy. Some of the site-specific factors associated with landform that directly influence forest understory development include: climate, landform position (e.g., slope, aspect and exposure), and soil moisture.

This study collected forest stand dynamics data within mid-latitude, temperate, mixed (deciduous and conifer) ecosystems. The sample sites have been impacted by manmade disturbances for roughly 350 years. Two of the study sites, however, show little anthropogenic impacts over the last 250 to 300 years. As compared to some other mid-latitude temperate forest regions in other parts of the world, particularly central and southern Europe, this period of human disturbance is very brief.

The typical forests sampled in the study exhibited either mixed hardwood or mixed hardwood/conifer species composition. Stand structures were typically representative of uneven-aged canopies with multi-layered canopies that included distinct dominant stems and one or more layers of intermediate and suppressed stems. The understory layers ranged from a few widely scattered stems to fairly dense stands of seedlings and saplings. The exceptions to these repre-

sentative hardwood and mixed stands were pine plantations. Where managed, the understory component at these sites was typically minimal. When left unmanaged, the understory density of these plantations was substantial.

4 Methodology

Field Data Collection Sites

Sample sites were selected based on prior forest sampling knowledge and experience within and around Central Virginia. While an attempt was made to randomly select plot locations consideration was given to ease of access. In addition, an effort was made to obtain samples from a wide variety of forest types (young and old-age stands, variable species composition, etc.). Nineteen field data collects were taken from 14 October 1999 through July 2000 in Central Virginia. Data were collected at 56 plot sites spread out over seven locations (Figure 1).

The field data collection sites were located in Northern and North Central Virginia on the eastern fringes of the Piedmont. The topography of the areas generally consists of flat fields to gently rolling slopes. Local relief is generally less than 100 ft (30.5 m). In a number of data collect areas, the landscape was more dissected as streams cut through forested areas. Soils of the region are generally Ultisols and Vertisols.

The plot locations and respective number of plots at each location were:

1. *Fort A.P. Hill, Bowling Green, VA.* Fort A.P. Hill is a U.S. Army training installation located approximately 15 to 20 mi (1 mi = 1.61 km) south of Fredericksburg, VA. The topography is generally flat, with numerous bottomlands and marshy areas. There are also locations on the Fort that present a more dissected landscape where creeks cut through forested areas (37 plots).
2. *Topographic Engineering Center (TEC), Alexandria, VA.* TEC is situated approximately 20 mi SSW of Washington, DC in southern Fairfax County. The topography surrounding TEC is generally flat with numerous marshy and swampy areas, many of them seasonal in nature (three plots).
3. *Caledon Natural Area, King George, VA.* This location is a special area set aside by the State of Virginia and managed by Virginia's Department of Conservation and Recreation. It is located approximately 25 mi east of Fredericksburg, VA. The land, a donation of a wealthy family, consists of forested hills and wetlands adjacent to the Potomac River. The forests on the property are described as second-growth stands (four plots).

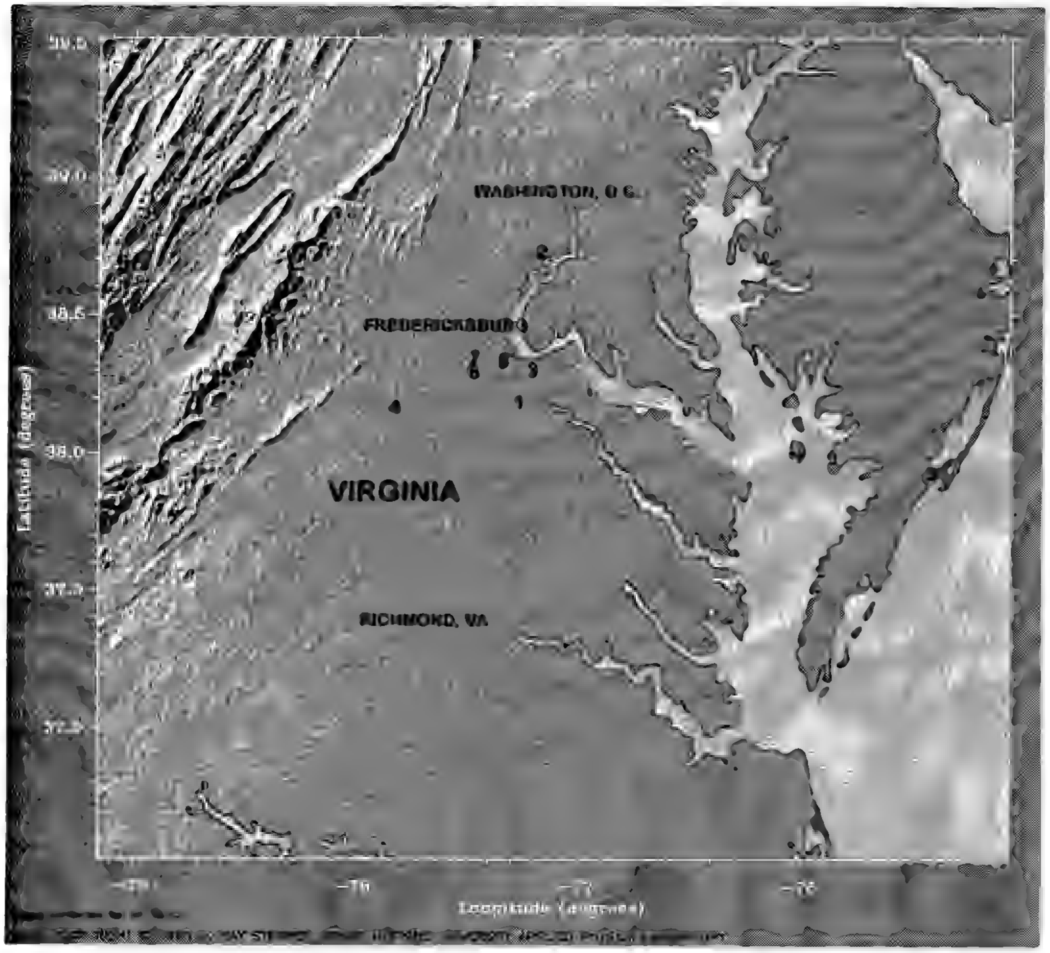

Figure 1. Data Collection Sites.

4. *Montpelier, VA.* Montpelier is located approximately 40 mi west southwest of Fredericksburg, VA. It is the former estate of President James Madison. (The grounds are managed by an historical foundation.) The topography is generally rolling. Numerous areas on the estate contain individual old-growth specimens and small, undisturbed old-growth stands (four plots).

5. *Fredericksburg Battlefield, Fredericksburg, VA.* This battlefield is located approximately 1 mi from downtown Fredericksburg, VA and is maintained by the National Park Service. The topography is flat to gently rolling. Pre-Civil War photographs of this site show an abundance of agricultural fields with minimal woody vegetation (two plots).

6. *Spotsylvania National Military Park, Fredericksburg, VA.* This site is located approximately 10 mi southwest of Fredericksburg, VA. The topography is flat to gently rolling. As with the Fredericksburg Battlefield, this area was composed of

agricultural fields during the Civil War. What woody vegetation that existed was cut down by troops for fuel and fortifications (two plots)

7. *Chancellorsville Battlefield, Fredericksburg, VA.* This site is located approximately 10 mi west of Fredericksburg, VA. The topography is primarily flat. Its history mirrors that of the previous two sites (four plots).

Plot Design

Fixed-area, circular plots were designed to accurately and precisely sample both the overstory and understory layers. Experience from previous forest sampling projects suggested a plot radius of 10 to 15 m. To minimize sampling efforts within each plot and to maximize the total number of plots a 10-m radius (~33 ft) was selected. Wenger (1984) recommends that, for forests in the eastern United States, sample plots should range from 1/50 to 1/25 hectare (ha). The 10-m radius plot is equivalent to a plot size of approximately 1/32-ha. Furthermore, given that this work has an ultimate application in forest attribute extraction from remotely sensed imagery, a 20-m diameter plot theoretically adequately characterizes both a SPOT 4 and Landsat ETM 7 pixel.

Data Collection Procedures

Overstory Stems

A plot center was established at a representative location within the selected forest stand. A small wire flag was placed in the ground to mark the center of the sampling area. Plot coordinates were obtained using a PLGR (GPS receiver). Flagging was then positioned at 10 m from the plot center at each of the 4 cardinal compass directions. Working clockwise from a dominant tree within the plot, the following attributes were recorded for each dominant and codominant overstory tree using standard measurement techniques (see Avery and Burkhart, 1994):

1. Distance from plot center (meters)
2. Azimuth (true north) using plot center as the reference (degrees)
3. Species
4. Diameter at breast height (cm)
5. Total height
6. Canopy closure

7. Crown diameter
8. Crown canopy class.

Overstory individuals were defined as all woody stems with a diameter at breast height (d.b.h.) greater than 4 in. (~10 cm). The distance and azimuth measures were collected to quantitatively calculate average minimum distance between the stems. This measure represents an estimate of stem spacing within the plot. Tree species was recorded. The d.b.h. measurements were collected using either a caliper or diameter tape. Trunk diameter is consistently measured at approximately 4.5 ft (1.37 m) above the ground. Precision was within 0.1 in (~0.25 cm). Tree height was measured using a clinometer. Precision was on the order of 1 ft (~0.3 m).

Canopy class describes the vertical position of each overstory crown with respect to the surrounding individuals. For statistical analysis in this study, the overstory was deemed to be only the dominant and codominant stems. The crowns of these stems can be readily seen by airborne platforms. Intermediate and suppressed stems, not viewable from above, were merged with the understory stems during analysis.

Definitions of each of the four crown canopy classes is provided by Smith (1962):

1. *Dominant*: Trees with crowns extending above the general level of the crown cover and receiving full light from above and partially from the side, larger than the average trees in the stand, and with crowns well developed, but possibly somewhat crowded on the sides.
2. *Codominant*: Trees with crowns forming the general level of the crown cover and receiving full light from above, but comparatively little from the sides, usually with medium-sized crowns more or less crowded on the sides.
3. *Intermediate*: Trees shorter than the dominant and codominant with crowns pushing into the crown cover, receiving little light from above and none from the sides, usually with small crowns considerably crowded on the sides.
4. *Suppressed*: Also known as overtopped, these trees have crowns that fall entirely below the general level of the crown cover, receiving no direct light either from above or from the sides

For all stems identified as either dominant or codominant, crown diameter was measured and recorded. Crown diameter was not measured for crowns classified as intermediate or suppressed. Two measurements were obtained, one representing the major crown axis and the other the minor crown axis. Crown axis is

determined by estimating the drip-line of the crown. These values were then summed and divided by 2 to obtain an average crown diameter. Precision was on the order of 1 ft (0.3 m).

Ancillary plot attributes recorded at each plot location included:

1. Slope (percent)
2. Aspect (degrees)
3. Landform type
4. Canopy closure (percent)
5. General soil description
6. Description of overall shrub/sapling, seedling, and herbaceous cover.

Understory Stems

For the purpose of this study, understory stems were defined as all woody individuals with d.b.h. less than 4 in (~10 cm) and total height greater than 6 ft (~1.8 m). Using these criteria, measured understory specimens consisted of saplings and taller shrubs. Species, height, crown diameter and d.b.h. were measured for all sampled understory stems. (Preliminary data analysis suggested that understory height and crown diameter showed practically no correlation with any other stand variables. Thus, these two measurements were not recorded on roughly one-third of the sample sites.)

Plant material that was less than 6 ft (~1.8 m) in total height consisted of tree seedlings, dwarf shrubs, and the herbaceous layer (grasses, forbs, and ferns). No direct measurements of this vegetation stratum were recorded. However, a description of these nonsampled understory vegetation members was noted in the plot logs.

Preliminary Data Management

All of the acquired plot information was entered onto an Excel spreadsheet and imported into Statistica (StatSoft, 1999) for manipulation and analysis. Summary statistics were then generated for each plot, including means, standard deviations, and variances for overstory and understory height, crown diameter, and d.b.h.

Overstory and understory stem densities were derived and reported as the total number of estimated stems per hectare (to convert to stems per acre, divide by 2.471). Mean minimum distance between the dominant and codominant stems was reported for each plot. Finally, a description of the species composition of each plot was used to classify the sample sites into broad vegetation types, including:

1. Pure hardwood
2. Mixed hardwood/pine
3. Mixed pine/hardwood
4. Pure pine.

Statistical Analysis

Due to the paucity of previous work on this subject found in the literature, the authors had no *a priori* hypotheses concerning the relationships between the overstory characteristics and understory stem density. Therefore, all measured variables (stem characteristics and plot attributes) were included in the analysis. The initial approach to uncovering relationships was through employment of *exploratory data analysis* (EDA) techniques. EDA is an approach to data analysis that postpones the usual assumptions about what kind of model the data follow with the more direct approach of allowing the data itself to reveal its underlying structure and model. Most EDA techniques are graphical in nature. Graphics provide analysts with open-minded exploration using their intuitive pattern-recognition capabilities. Primary EDA techniques include scatterplots, histograms, residual plots, probability plots, and plots of simple statistics such as means and standard deviations. The data, therefore, are used to suggest the appropriate model(s) that fit the data itself.

5 Results

Summary Statistics

A total of 4314 individual trees were measured—1051 overstory stems and 3263 understory stems—across 56 individual plots. Table 1 lists the total number of overstory stems sampled by species. Loblolly pine (*Pinus taeda*) was the most frequently encountered softwood species (22.4 percent), while white oak (*Quercus alba*) was the most frequently sampled hardwood species (18.8 percent). A total of 22 unique deciduous species were encountered in the overstory while only five different conifer species were found across all 56 plots. Table 2 lists the number of understory stems tallied by species. American holly (*Ilex opaca*), one of three evergreen hardwood species commonly found in North America, was the most frequently sampled understory species (17.5 percent). Highbush blueberry (*Vaccinium corymbosum*) and dogwood (*Cornus florida*) were the second and third, respectively, most frequently encountered understory species. Virginia pine (*Pinus virginiana*), loblolly pine (*P. taeda*), and eastern red cedar (*Juniperus virginiana*) were the only conifer species occupying the understory. Their small numbers can be attributed to the fact that they are all highly shade intolerant.

Table 3 displays summary univariate overstory statistics for each plot. Plots 9d and 12c, both pine plantations, support the greatest density of overstory stems at 923 and 924 per hectare, respectively. The plots with the fewest number of stems per hectare included 19b (64 stems per hectare), plot 5d (95 stems per hectare), and plot 7a (96 stems per hectare). Each of these sites was oak dominated.

Mean stem diameter (d.b.h.) was calculated for each plot. The sites with the greatest average stem diameters included plots 19a-d. These oak dominated stands averaged in diameter between 18.2 and 32.2 in. Plots 12c and 9a displayed the small average stem diameters with 5.1 to 6.4 in., respectively.

The greatest stand densities as measured by basal area are found in plots 19a–19d, with estimated total basal areas per hectare of 12.9 to 16.3 sq ft (1.2 to 1.5 m^2). These sites all support oak dominated overstories. Also, plots 4a and 4b, older second-growth stands in Caledon Natural Area, have basal areas of 14.7 and 16.6 sq ft (1.37 and 1.54 m^2) respectively.

Table 1. Overstory Stems—Species and Counts.

<table>
<tr><th>Common Name</th><th>Latin Name</th><th>Stem Count</th><th>Percentage</th></tr>
<tr><td>loblolly pine</td><td>Pinus taeda</td><td>235</td><td>22.4</td></tr>
<tr><td>white oak</td><td>Quercus alba</td><td>198</td><td>18.8</td></tr>
<tr><td>Virginia pine</td><td>Pinus virginiana</td><td>105</td><td>10.0</td></tr>
<tr><td>yellow poplar</td><td>Liriodendron tulipifera</td><td>104</td><td>9.9</td></tr>
<tr><td>sweet gum</td><td>Liquidambar styraciflua</td><td>70</td><td>6.7</td></tr>
<tr><td>southern red oak</td><td>Quercus falcata</td><td>55</td><td>5.2</td></tr>
<tr><td>red maple</td><td>Acer rubrum</td><td>50</td><td>4.8</td></tr>
<tr><td>beech</td><td>Fagus grandifolia</td><td>43</td><td>4.1</td></tr>
<tr><td>hickory</td><td>Carya tomentosa</td><td>40</td><td>3.8</td></tr>
<tr><td>black oak</td><td>Quercus velutina</td><td>34</td><td>3.2</td></tr>
<tr><td>black gum</td><td>Nyssa sylvatica</td><td>23</td><td>2.2</td></tr>
<tr><td>chestnut oak</td><td>Quercus prinus</td><td>20</td><td>1.9</td></tr>
<tr><td>big tooth aspen</td><td>Populus grandidentata</td><td>18</td><td>1.7</td></tr>
<tr><td>post oak</td><td>Quercus stellata</td><td rowspan="14">56</td><td rowspan="14">5.3</td></tr>
<tr><td>scarlet oak</td><td>Quercus coccinea</td></tr>
<tr><td>northern red oak</td><td>Quercus rubra</td></tr>
<tr><td>dogwood</td><td>Cornus florida</td></tr>
<tr><td>pitch pine</td><td>Pinus rigida</td></tr>
<tr><td>river birch</td><td>Betula nigra</td></tr>
<tr><td>persimmon</td><td>Diospyros virginiana</td></tr>
<tr><td>sassafras</td><td>Sassafras albidum</td></tr>
<tr><td>longleaf pine</td><td>Pinus palustris</td></tr>
<tr><td>sycamore</td><td>Plantanus occidentalis</td></tr>
<tr><td>cherry</td><td>Prunus serotina</td></tr>
<tr><td>willow oak</td><td>Quercus phellos</td></tr>
<tr><td>blackjack oak</td><td>Quercus marilandica</td></tr>
<tr><td>eastern red cedar</td><td>Juniperus virginiana</td></tr>
<tr><td colspan="2" align="right">Totals</td><td>1051</td><td>100.0</td></tr>
</table>

The sites supporting the lowest basal areas included 4c, with only 1.97 sq ft (0.18 m^2), 18a, with 3.01 sq ft (0.28 m^2) and 12c, with 4.26 sq ft (0.4 m^2). The first two plots, 4c and 18a, were hardwood dominated, while 12c was a young, unmanaged pine plantation.

Plots 19 (a-d) and 4 (a-c) maintained the overall tallest stands, with mean overstory heights ranging from 103 to 124 ft (31.4 to 37.8 m). The shortest stands sampled were in plot 12c, a young, unmanaged pine plantation with an average total height of only 27.3 ft (8.3 m), and plot 9a, another pine dominated site supporting stems only 41.3 ft (12.6 m) tall on average. Plots 16a-c and 17a-d were pine plantations with average overstory canopy heights from 54.0 to 77.9 ft (23.7 m).

Table 2. Understory Stems—Species and Counts.

Common Name	Latin Name	Stem Count	Percentage
holly	*Ilex opaca*	570	17.5
highbush blueberry	*Vaccinium corymbosum*	380	11.6
dogwood	*Cornus florida*	376	11.5
southern red oak	*Quercus falcata*	365	11.2
sweet gum	*Liquidambar styraciflua*	337	10.3
beech	*Fagus grandifolia*	210	6.4
white oak	*Quercus alba*	200	6.1
hickory	*Carya tomentosa*	194	5.9
red maple	*Acer rubrum*	136	4.2
black oak	*Quercus velutina*	70	2.1
black gum	*Nyssa sylvatica*	64	2.0
big tooth aspen	*Populus grandidentata*	57	1.7
mountain laurel	*Kalmia latifolia*	53	1.6
sassafras	*Sassafras albidum*	50	1.5
yellow poplar	*Liriodendron tulipifera*	32	1.0
Virginia pine	*Pinus virginiana*	32	1.0
magnolia	*Magnolia virginia*	25	0.8
chestnut oak	*Quercus prinus*	20	0.6
cherry	*Prunus serotina*	18	0.6
loblolly	*Pinus taeda*	18	0.6
hornbeam	*Carpinus caroliniana*	14	0.4
willow oak	*Quercus phellos*	11	0.3
eastern red cedar	*Juniperus virginiana*	9	0.3
spicebush downy serviceberry devil's walking stick striped maple American chestnut	*Lindera benzoin* *Amelanchier arborea* *Aralia spinosa* *Acer pensylvanicum* *Castanea dentata*	22	0.7
	Totals	**3263**	**100.0**

The final overstory parameter of importance is average crown diameter. The largest average crown diameters were measured in 4b and 4c, both with 61.3 ft (18.7 m) on average. These plots were dominated by sweetgum and oak, respectively, and were located at Caledon Natural Area, an old, second-growth forest. The smallest crown diameters were found in plot 9a at 11.5 ft (3.5 m). Many more plots possessed an average crown diameter between 12 and 15 ft (3.7 and 4.6 m) wide. All the small crown plots were established within pine plantations.

Table 4 presents summary univariate understory statistics by plot. As stated above, the number of understory variables collected in each plot was reduced a little more than half way through the sampling.

Table 3. Overstory Summary Statistics.

Plot ID	Stems Per Hectare	Mean Minimum Distance (ft)*	Mean Height (ft)	Standard Deviation Height	Mean Crown Diameter (ft)	Standard Deviation Crown	Mean d.b.h. (in)	Standard Deviation d.b.h.	Basal Area (sq ft)	Dominant Species
1a	159	18.4	94.0	5.5	33.6	10.2	16.2	2.8	7.34	oak
1b	159	21.3	90.0	16.3	41.8	17.0	18.4	11.1	9.40	oak
1c	191	11.5	81.7	6.8	30.3	6.0	15.6	2.9	8.21	oak-hickory
1d	127	19.7	75.0	4.1	32.6	9.4	17.0	3.6	6.49	oak-pine
2a	350	7.4	68.3	5.4	18.0	5.6	8.8	2.1	5.34	poplar
2b	287	15.1	90.3	11.6	27.5	5.0	13.6	3.3	9.51	sweet gum
3a	382	9.4	76.3	12.0	23.8	9.0	11.8	3.6	9.89	sweet gum
3b	312	6.2	75.5	12.6	23.7	6.0	11.3	4.4	7.93	poplar
4a	159	18.4	124.0	15.2	42.7	15.3	22.3	7.1	14.67	sweet gum
4b	159	13.1	120.0	9.6	61.3	10.4	23.3	5.6	16.56	sweet gum
4c	32	26.2	122.5	9.6	61.3	10.4	23.3	5.6	1.97	oak
5a	159	19.7	112.0	8.4	38.3	10.1	21.2	7.2	13.38	oak
5b	127	13.1	103.0	10.1	42.0	19.2	18.8	7.2	8.51	oak
5c	287	9.8	89.4	4.6	24.8	10.9	11.6	5.4	7.89	poplar
5d	95	26.2	105.0	5.8	35.0	5.7	14.5	4.4	4.90	oak-hickory
6a	287	16.4	107.4	7.0	27.1	5.9	15.6	2.2	12.09	poplar
6b	191	10.3	115.8	10.7	36.0	15.5	19.8	7.8	14.43	oak
6c	414	13.1	72.9	7.7	19.0	5.9	9.4	3.6	7.13	pine
7a	96	21.9	106.7	5.8	38.3	4.0	21.7	5.5	8.01	oak- poplar
7b	223	10.8	100.0	8.2	28.8	9.5	14.6	4.2	8.76	oak-hickory
7c	255	8.5	97.1	10.4	28.3	8.8	15.6	4.1	12.75	oak
8a	127	27.2	107.5	12.6	46.3	10.0	18.8	4.7	8.03	hick
8b	191	10.8	105.0	8.4	23.6	5.8	13.2	3.3	5.97	pine-poplar
8c	255	14.8	110.0	11.0	36.4	9.1	17.3	2.8	13.33	oak

Plot ID	Stems Per Hectare	Mean Minimum Distance (ft)*	Mean Height (ft)	Standard Deviation Height	Mean Crown Diameter (ft)	Standard Deviation Crown	Mean d.b.h. (in)	Standard Deviation d.b.h.	Basal Area (sq ft)	Dominant Species
9a	732	6.9	41.3	10.4	11.5	4.6	6.4	2.9	6.18	pine
9b	605	6.1	63.2	6.5	15.4	4.6	8.8	1.9	8.31	pine
9c	446	9.8	92.2	6.7	24.2	7.4	12.3	2.0	7.64	oak
9d	923	7.4	58.1	3.9	14.1	2.0	8.3	1.8	11.39	pine
10a	287	14.0	66.7	5.0	21.6	5.9	11.2	3.6	6.73	pine
10b	191	19.7	95.8	3.8	33.7	14.1	16.6	5.5	9.83	oak
11a	255	12.6	91.0	7.2	24.2	8.4	14.2	2.9	9.11	oak
11b	127	26.3	94.3	7.2	27.5	6.5	15.8	1.5	5.45	pine
12a	318	10.9	80.0	7.8	21.0	8.3	11.0	3.9	7.27	oak
12b	191	15.8	105.3	12.8	30.6	5.9	15.7	3.9	8.44	oak
12c	924	6.0	27.8	2.5	11.7	1.6	5.1	0.8	4.26	pine
13a	446	10.5	89.9	5.1	22.3	5.3	10.5	1.4	7.89	black gum
13b	159	18.0	116.0	5.5	30.2	6.7	16.7	3.1	7.8	oak
13c	159	20.0	115.0	5.5	33.8	9.8	17.2	4.4	10.2	oak
14a	318	10.2	90.0	5.8	22.1	7.2	12.8	2.8	9.36	oak
14b	191	13.1	88.3	5.2	30.7	12.2	16.7	4.3	9.60	oak-pine
14c	223	16.0	68.4	5.7	25.9	8.3	11.3	3.2	5.91	oak
14d	255	12.8	70.6	6.8	28.8	8.2	13.5	3.5	8.48	oak
15a	637	6.8	61.2	6.3	13.5	3.1	7.8	2.3	7.22	sweet gum
15b	605	11.5	69.6	7.4	14.9	5.9	9.9	3.6	8.93	pine
16a	510	9.2	77.9	5.0	18.7	5.4	11.4	2.4	11.03	pine
16b	732	7.5	58.0	5.0	14.2	4.0	8.1	2.8	8.76	pine
16c	892	5.0	57.0	3.5	12.5	2.9	7.3	2.1	8.37	pine
17a	605	6.5	72.4	5.5	14.7	4.6	10.4	2.1	10.36	pine
17b	732	7.5	60.9	2.7	13.0	3.8	8.6	2.3	9.86	pine

Plot ID	Stems Per Hectare	Mean Minimum Distance (ft)*	Mean Height (ft)	Standard Deviation Height	Mean Crown Diameter (ft)	Standard Deviation Crown	Mean d.b.h. (in)	Standard Deviation d.b.h.	Basal Area (sq ft)	Dominant Species
17c	605	7.5	54.0	5.4	12.1	2.8	7.6	2.1	6.46	pine
18a	255	10.2	116.0	9.9	24.0	7.9	16.6	4.3	3.01	poplar
19a	191	13.8	117.8	9.4	40.0	10.6	21.8	5.4	20.4	oak
19b	64	19.8	123.0	3.6	48.1	17.3	24.1	3.7	12.92	oak
19c	127	18.4	118.0	16.0	51.7	18.1	32.2	16.8	16.29	oak
19d	191	13.1	101.3	7.9	36.4	9.0	18.3	5.6	14.35	oak
19e	127	21.3	110.9	15.0	35.4	6.8	19.2	5.3	15.75	oak

* 1 ft = 0.305 m; 1 in. = 2.54 cm; 1 sq ft = 0.093 m^2

Table 4. Understory Summary Statistics.

Plot ID	Density Per ha All Stems	Density Per ha >1.0 in d.b.h.	Mean Height (ft)*	Standard Deviation Height	Mean Crown Diameter (ft)	Standard Deviation Crown	Mean d.b.h. (in)	Standard Deviation d.b.h.	Basal Area (sq ft)	Dominant Species	Plot Slope	Plot Aspect
1a	1395	853	10.8	6	8.3	3.7	1.3	0.88	0.41	dogwood	5	44
1b	2293	NR	NR	NR	NR	NR	NR	NR	NR	dogwood	0	none
1c	1145	NR	NR	NR	NR	NR	NR	NR	NR	dogwood	6	95
1d	1305	NR	NR	NR	NR	NR	NR	NR	NR	sweetgum	1	174
2a	1369	1178	15.1	9.5	8.4	3.5	1.8	1.1	0.85	sweetgum	2	180
2b	1692	1019	10.8	6.2	6.3	4.1	1.0	1.5	0.38	maple	1	360
3a	1719	987	13.4	8.1	6.6	3.9	1.2	0.9	0.48	riverbirch	2	135
3b	2451	2038	16.7	9.1	8.9	5.2	1.6	1.0	1.25	oak	25	225
4a	797	701	18.5	9.3	13.7	9.7	2.0	0.9	0.48	dogwood	4	360
4b	568	540	22.9	12.8	16.4	8.7	2.2	1.3	0.37	holly	5	225
4c	1305	987	17.3	10.1	13.2	8.2	1.5	1.0	0.59	beech	20	225

Plot ID	Density Per ha All Stems	Density Per ha >1.0 in d.b.h.	Mean Height (ft)*	Standard Deviation Height	Mean Crown Diameter (ft)	Standard Deviation Crown	Mean d.b.h. (in)	Standard Deviation d.b.h.	Basal Area (sq ft)	Dominant Species	Plot Slope	Plot Aspect
5a	1559	1369	13.0	4.0	7.1	3.7	1.6	0.7	0.79	dogwood	11	12
5b	1560	1369	18.1	7.9	9.0	5.1	1.8	0.9	0.91	oak	15	270
5c	1151	414	15.3	10.5	10.1	10.3	1.4	0.9	0.21	oak	18	200
5d	1209	796	12.0	4.9	5.6	3.0	1.1	0.6	0.30	oak	20	294
6a	1144	765	12.2	7.1	7.0	4.4	1.3	0.7	0.41	holly	7	354
6b	1973	1146	13.5	5.3	7.9	4.4	1.1	0.7	0.59	beech	12	300
6c	1178	986	19.1	10.6	7.8	3.9	1.7	0.9	0.58	holly	1	40
7a	1369	1146	15.6	7.0	10.7	5.2	1.9	0.9	0.71	dogwood	15	320
7b	2229	1720	12.4	5.0	6.2	2.8	1.3	0.7	0.68	dogwood	0	none
7c	1240	1177	15.7	7.6	8.8	4.3	2.1	1.1	0.93	holly	14	80
8a	1369	1019	15.4	7.5	11.0	7.9	1.4	0.9	0.44	beech	15	320
8b	2293	1592	18.2	9.9	8.3	4.8	1.3	0.8	0.76	beech	1	360
8c	1464	1147	14.4	7.6	6.4	2.5	1.6	0.9	0.66	holly	6	230
9a	5698	4045	23.4	8.7	7.3	2.7	1.6	0.8	3.18	aspen	2	336
9b	4106	2770	20.3	9.1	7.3	4.1	1.4	0.9	1.91	oak	4	200
9c	1462	1177	10.0	4.2	5.3	2.9	1.3	0.7	0.44	holly	10	140
9d	4296	3407	22.9	11.1	6.4	2.7	1.4	0.7	1.72	aspen	0	none
10a	2357	1625	15.7	8.8	5.2	3.3	1.3	0.8	0.91	hickory	0	none
10b	1847	1242	12.1	5.3	7.3	3.3	1.4	0.9	0.83	holly	7	70
11a	1688	1243	10.6	5.0	6.4	2.6	1.3	0.6	0.50	holly	13	307
11b	1529	542	9.0	4.0	3.1	1.6	0.9	0.6	0.28	sweetgum	0	none
12a	2707	1911	12.4	6.1	6.9	4.9	1.3	0.7	0.90	holly	7	14
12b	1369	700	13.9	15.3	6.0	5.5	1.5	2.9	0.35	holly	5	260
12c	6210	3025	13.8	7.7	4.6	2.5	1.1	0.8	2.07	oak	0	none
13a	4936	510	8.0	4.0	2.9	2.0	0.6	0.5	0.44	holly	10	270

Plot ID	Density Per ha All Stems	Density Per ha >1.0 in d.b.h.	Mean Height (ft)*	Standard Deviation Height	Mean Crown Diameter (ft)	Standard Deviation Crown	Mean d.b.h. (in)	Standard Deviation d.b.h.	Basal Area (sq ft)	Dominant Species	Plot Slope	Plot Aspect
13b	1465	796	14.1	6.0	7.2	3.8	1.5	0.7	0.57	holly	14	280
13c	1114	987	15.6	6.9	8.0	4.6	1.9	0.9	0.69	oak	14	110
14a	1910	1528	15.3	6.6	8.1	4.8	1.5	0.8	0.88	oak	7	330
14b	2006	1688	16.9	8.7	6.9	3.3	1.6	0.8	0.95	oak	7	240
14c	2675	1656	18.1	10.4	7.6	4.5	1.4	0.8	1.05	oak	4	328
14d	1210	701	12.9	6.8	5.8	2.4	1.3	0.8	0.43	oak	3	4
15a	3121	2739	NR	NR	NR	NR	1.5	0.7	1.31	dogwood	0	none
15b	1911	860	NR	NR	NR	NR	0.9	0.8	0.37	oak	3	320
16a	1847	1273	NR	NR	NR	NR	1.2	0.7	0.54	oak	2	310
16b	2452	2292	NR	NR	NR	NR	1.7	0.8	1.51	oak	8	360
16c	2389	1974	NR	NR	NR	NR	1.4	0.8	1.04	dogwood	0	none
17a	2994	1910	NR	NR	NR	NR	1.3	0.8	1.08	sweetgum	0	none
17b	3822	3057	NR	NR	NR	NR	1.5	0.8	1.65	dogwood	0	none
17c	2420	2006	NR	NR	NR	NR	1.4	0.7	0.99	oak	4	230
18a	764	797	NR	NR	NR	NR	1.6	0.7	0.28	maple	2	80
19a	1274	987	NR	NR	NR	NR	1.4	0.8	0.53	holly	12	80
19b	2134	1497	NR	NR	NR	NR	1.8	0.9	1.26	holly	12	20
19c	3503	1943	NR	NR	NR	NR	1.3	0.9	1.88	holly	8	80
19d	2102	1369	NR	NR	NR	NR	1.5	0.9	0.88	holly	5	240
19e	1720	1241	NR	NR	NR	NR	1.7	0.8	0.85	holly	5	140

* 1 ft = 0.305 m; 1 in. = 2.54 cm; 1 sq ft = 0.093 m^2

Therefore, the only parameters that were consistently sampled within all 56 sites were the density of understory stems and d.b.h. The minimum estimated density of 568 stems per hectare was recorded in plot 4b which maintained a sweet gum overstory. The understory species in plot 4b were dominated by American holly. The greatest understory density was found in plot 12c with an estimate 6210 understory stems per hectare under a pure pine canopy in a young unmanaged plantation. The dominant understory species in this plantation site was southern red oak. As a whole, these summary statistics suggest an adequate representation to perform a preliminary investigation of the potential relationships between forest understory density to overstory parameters.

Exploratory Data Analyses

EDA techniques revealed a number of interesting relationships and structures between overstory characteristics and understory stem density. More classical statistical techniques were then employed. Classification techniques were used to try to organize the data into meaningful groupings. Hierarchical cluster analysis (joining-tree clustering) and nonhierarchical clustering (k-means) were employed to uncover natural clusters or groups in the data. Discriminant analysis was then used in an effort to determine the most important variables that discriminate between groups. These techniques, it was hoped, would divide the groups into those with like overstory characteristics enabling the examination of the corresponding understory stem densities in each group. The aforementioned techniques were also performed on subsets of the data. The 56 plots were divided by observable break-points in the height, crown, and d.b.h. distributions. The plots were additionally divided by species and combinations of species. This proved less than successful primarily because of the small number of data points used in the subset analyses.

The results of these analyses determined that using summarized data for all 56 plots was the best approach in developing preliminary predictive relationships. Then both simple and multiple regression were performed on the plot data.

Regression Results

The following discussion presents the results of both simple and multiple regression in estimating understory stem density. For the purposes of this study, understory stems were limited to those with d.b.h. values $\geq$1.0 in ($\geq$2.54 cm) and height $\geq$6.0 ft (~1.8 m). They also included the intermediate and suppressed

overstory stems, which cannot be viewed from above. This excludes many of the multi-stemmed shrubs. In all cases, simple regression took the form of a single term function with intercept. Examined first were the relationships between the measured parameters of the overstory itself. Next, all single overstory parameters are regressed against understory stem density. Finally, multiple regression was used to estimate the understory stem density.

Overstory Structural Relationships—Single Predictor (Independent) Variable

The first focus was on the overstory itself. This is what can be directly observed and measured by the analyst. As shown by the scatterplot patterns in Figures 2 through 9, the overstory exhibits a high degree of structure. If the overstory structure were purely random, then the relationships between the measured overstory and the understory might very well be nonexistent. Regressions were performed using Version 4.0 of TableCurve 2D (SPSS, 1997). This software processes x,y data points with over 8000 linear and nonlinear equations to determine a best-fit. It was decided to limit the body of potential equations to single and two term linear functions. Hence, each of the best-fit equations appearing below was selected from a body of over 1600 linear equations.

In addition to the form of the best-fit equation and the "a" and "b" coefficients, each graph contains a number of summary statistics. The coefficient of determination, r^2, indicates the proportion of variability in the dependent variable that is explained by the independent (predictor) variable. The Adj (adjusted) r^2 attempts to correct the r^2 to more closely reflect the goodness of the fit of the model. It incorporates the number of cases and number of independent variables. The standard error of the estimate (S.E.E.) is a measure of the dispersion of the observed values about the regression line. The "F" value (Fstat) shows how well the regression model fits the data. If the probability associated with this value is small, one can reject the hypothesis that the r^2 value = 0.

Figure 2 shows the relationship between overstory stem density and overstory mean height for the 56 forest plots. Older forests are those that appear in the upper left-hand portion of the graph. Younger forests are shorter and have higher overstory stem densities and appear in the lower right-hand portion of the graph. The relationship exhibits a moderate r^2 value of ~0.69.

Figure 3 shows the relationship between the overstory stem density per hectare and overstory mean crown diameter for the 56 forest plots. Older forests appear in the upper left-hand corner of the graph and younger forests in the lower right-hand corner of the graph. The relationship exhibits a moderate r^2 of 0.72.

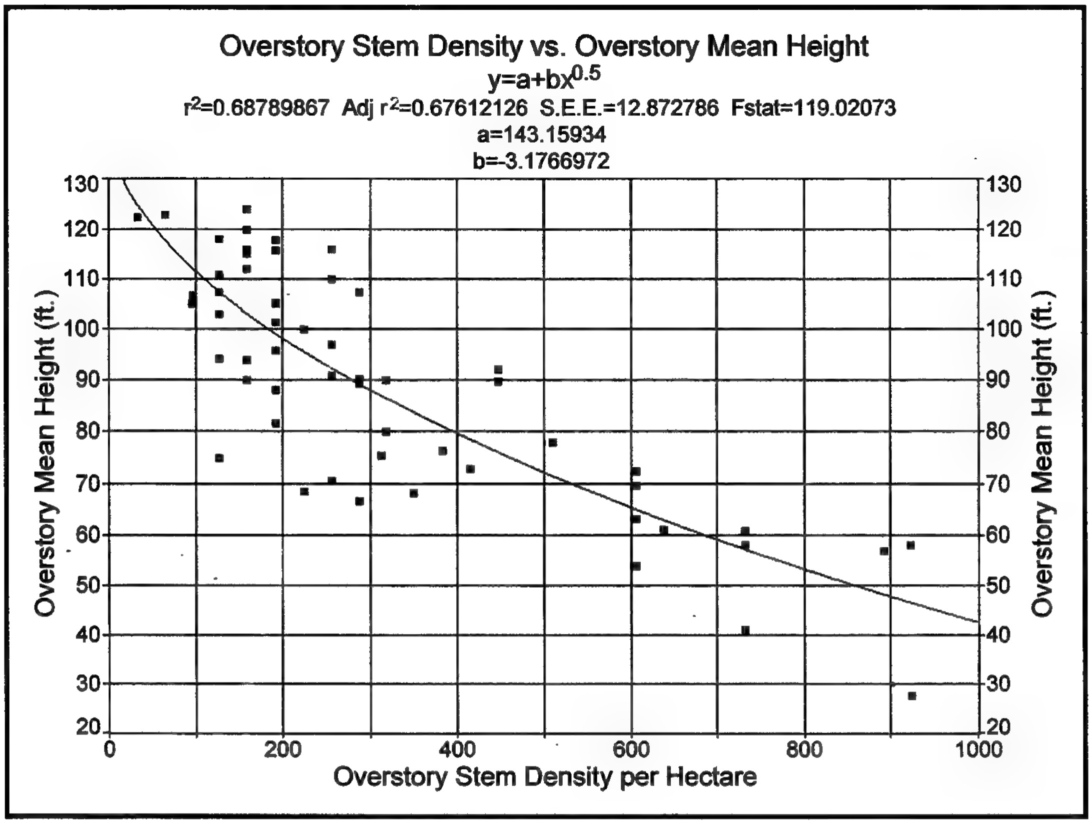

Figure 2. Overstory Stem Density vs. Overstory Mean Height.

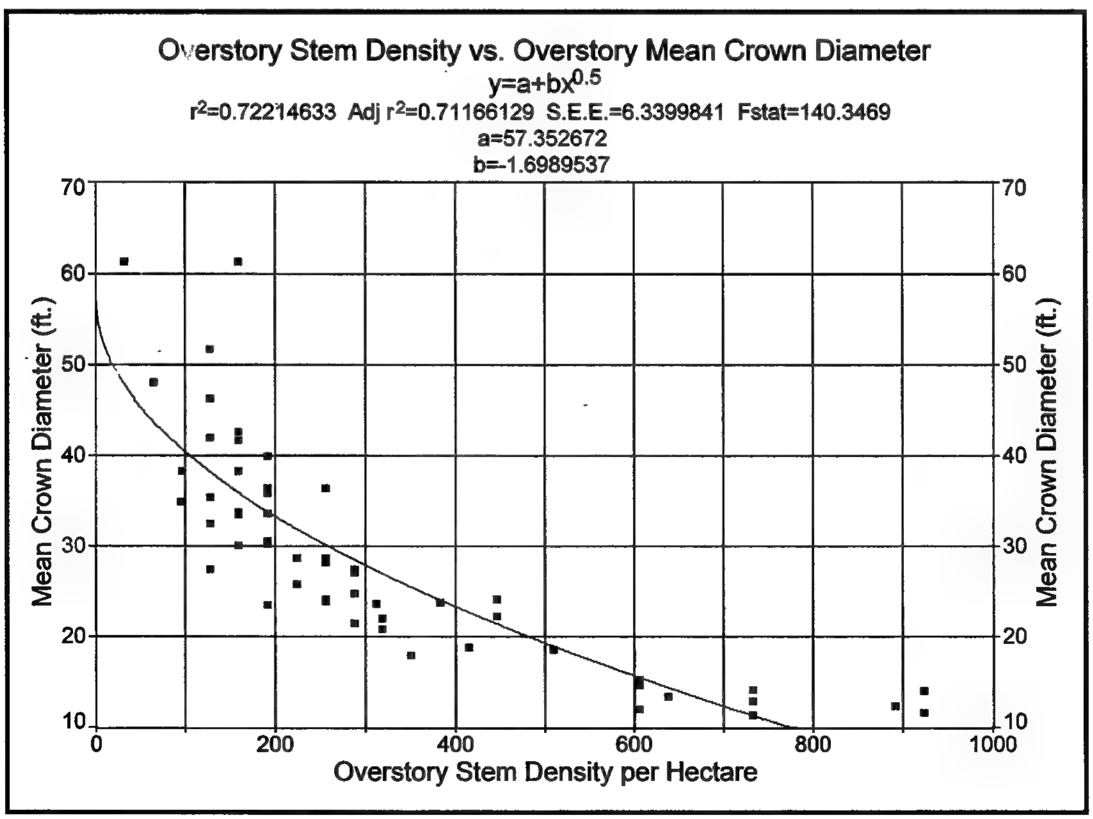

Figure 3. Overstory Stem Density vs. Overstory Mean Crown Diameter.

Figure 4 shows the relationship between the overstory stem density per hectare and overstory mean d.b.h. for the 56 forest plots. Older forests appear in the upper left-hand corner of the graph and younger forests in the lower right-hand corner of the graph. The relationship exhibits a moderate r^2 of ~0.77.

Figure 5 shows the relationship between the overstory stem density per hectare and the mean minimum distance of the dominant and codominant stems for the 56 forest plots. Older forests appear in the upper left-hand corner of the graph and younger forests in the lower right-hand corner of the graph.

Figure 6 shows the relationship between the overstory mean height and the overstory mean crown for the 56 forest plots. Older forests appear in the upper right-hand corner of the graph and younger forests in the lower left-hand corner of the graph.

Figure 7 shows the relationship between the overstory mean height and the overstory mean d.b.h. for the 56 forest plots. Older forests appear in the upper right-hand corner of the graph and younger forests in the lower left-hand corner of the graph.

Figure 8 shows the relationship between the overstory mean crown diameter and the overstory mean d.b.h. for the 56 forest plots. Older forests appear in the upper right-hand corner of the graph and younger forests in the lower left-hand corner of the graph. The r^2 is 0.87, the highest for all of the overstory relationships.

The results shown in Figure 8 mirror those of Krause, Puffenberger, and Campbell (1999) in their study of crown diameter-d.b.h. relationships. It is interesting to note that the 1999 study only considered trees with round, uniform crowns, whereas this study incorporated all overstory trees regardless of crown uniformity. The simple linear relationship still holds true.

Figure 9 shows the relationship between the overstory mean height and the mean minimum distance of the dominant and codominant stems for the 56 forest plots. Older forests appear in the upper right-hand corner of the graph and younger forests in the lower left-hand corner of the graph. This relationship is marginal as the residuals are highly heteroskedastic (fanning out when the mean height > 60 ft [18.3 m]) and the r^2 is quite poor (0.40).

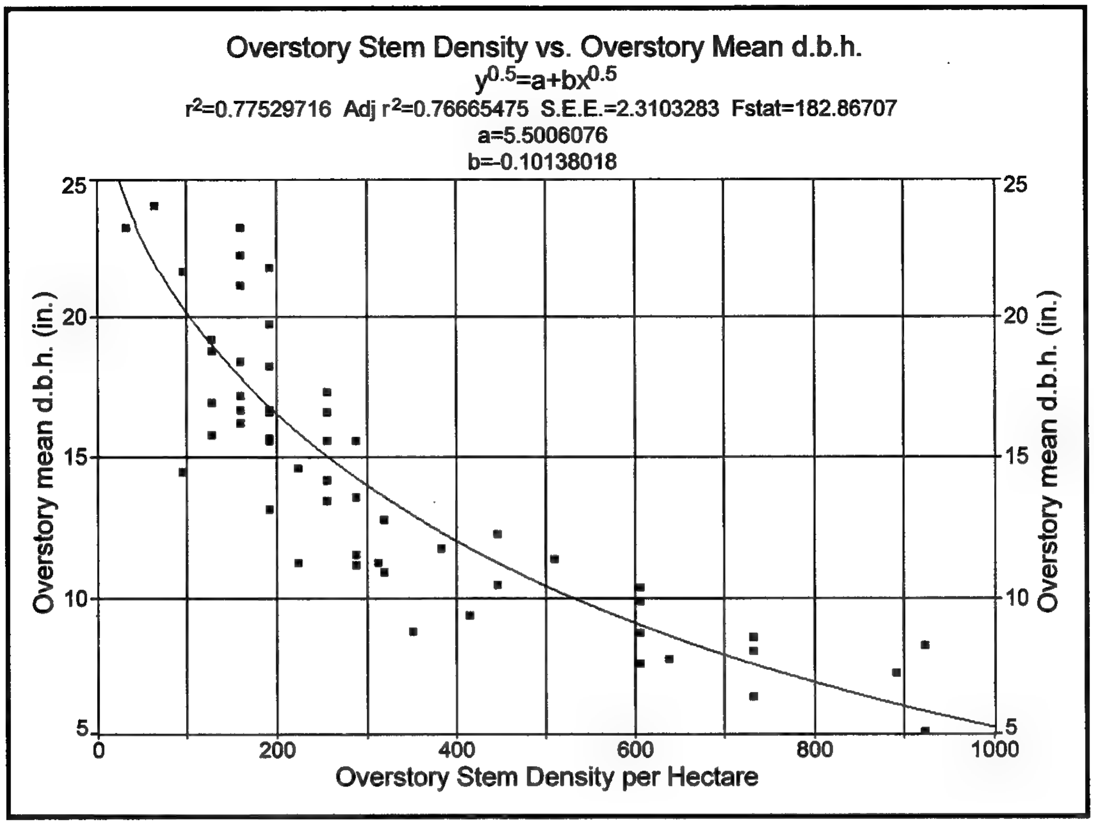

Figure 4. Overstory Stem Density vs. Overstory d.b.h.

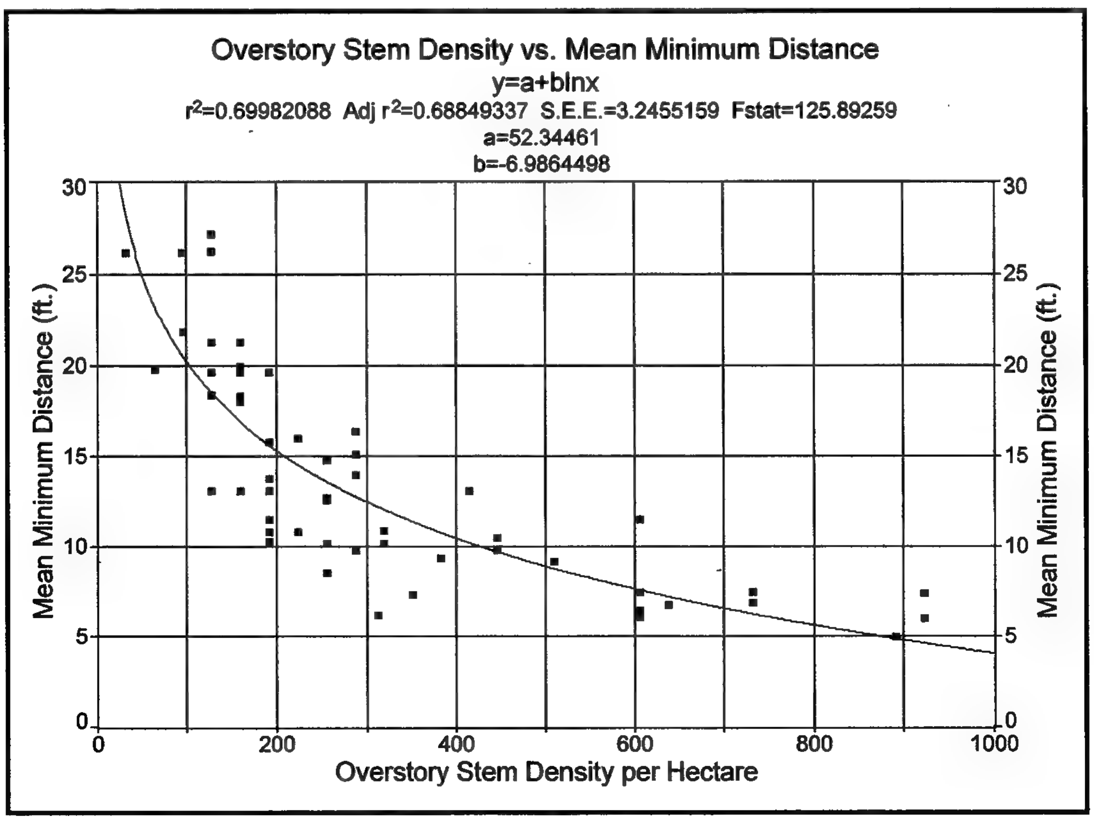

Figure 5. Overstory Stem Density vs. Mean Minimum Distance.

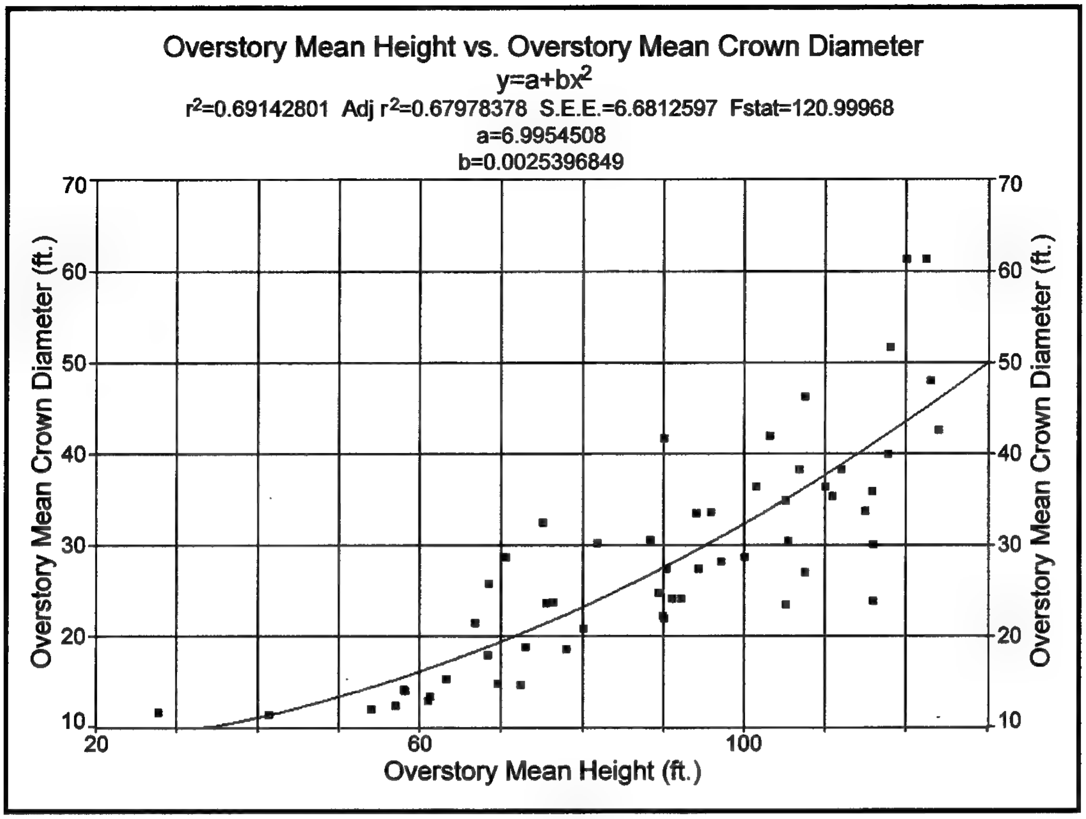

Figure 6. Overstory Mean Height vs. Overstory Mean Crown Diameter.

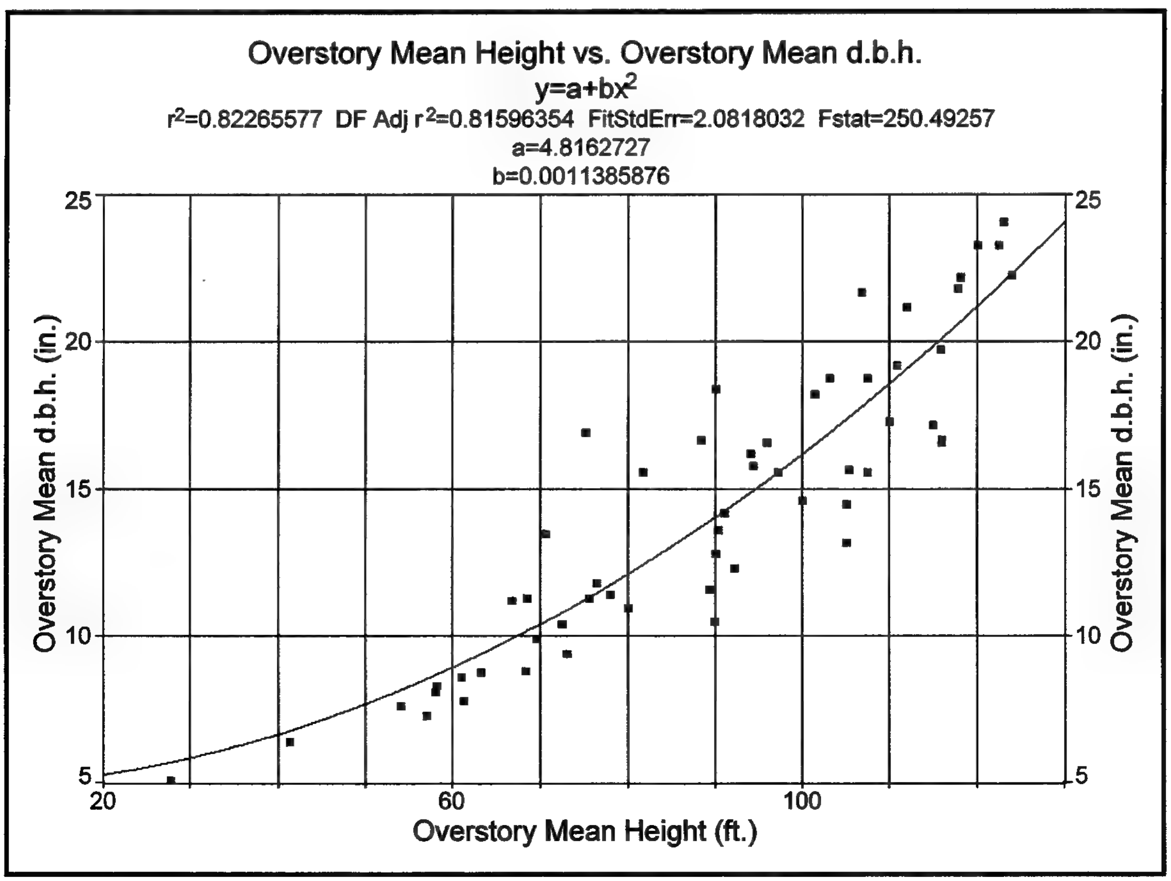

Figure 7. Overstory Mean Height vs. Overstory Mean d.b.h.

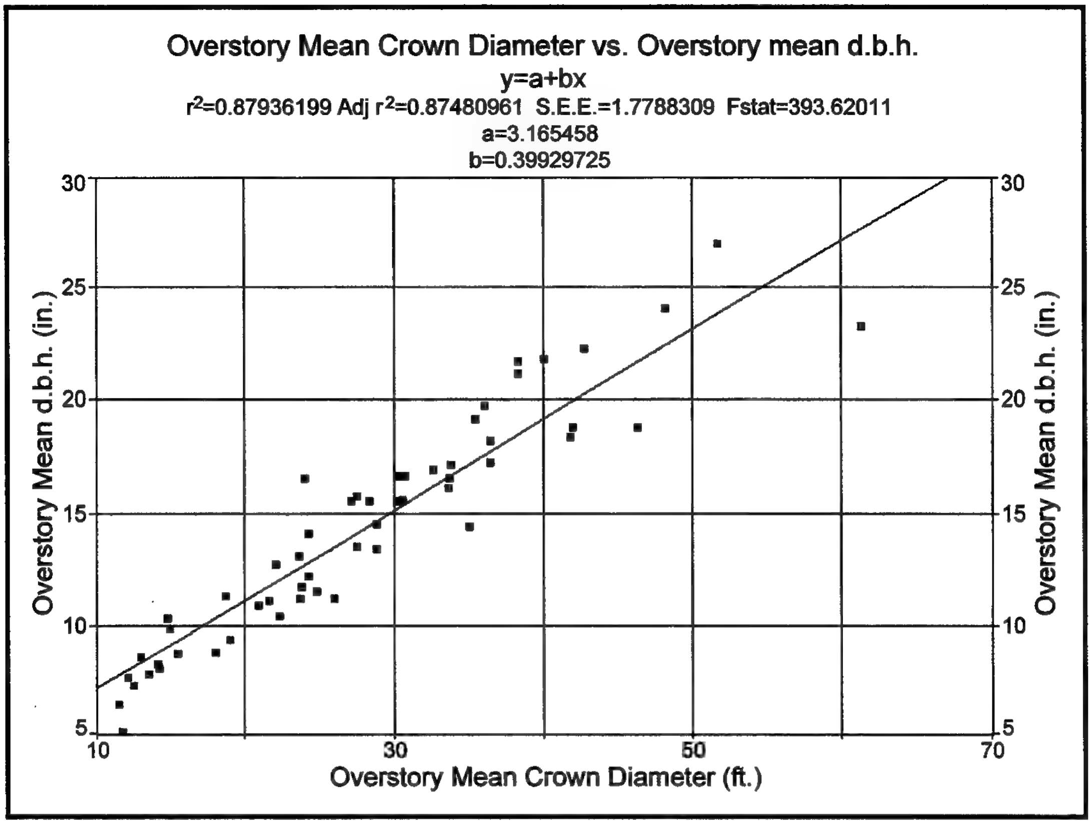

Figure 8. Overstory Mean Crown Diameter vs. Overstory Mean d.b.h.

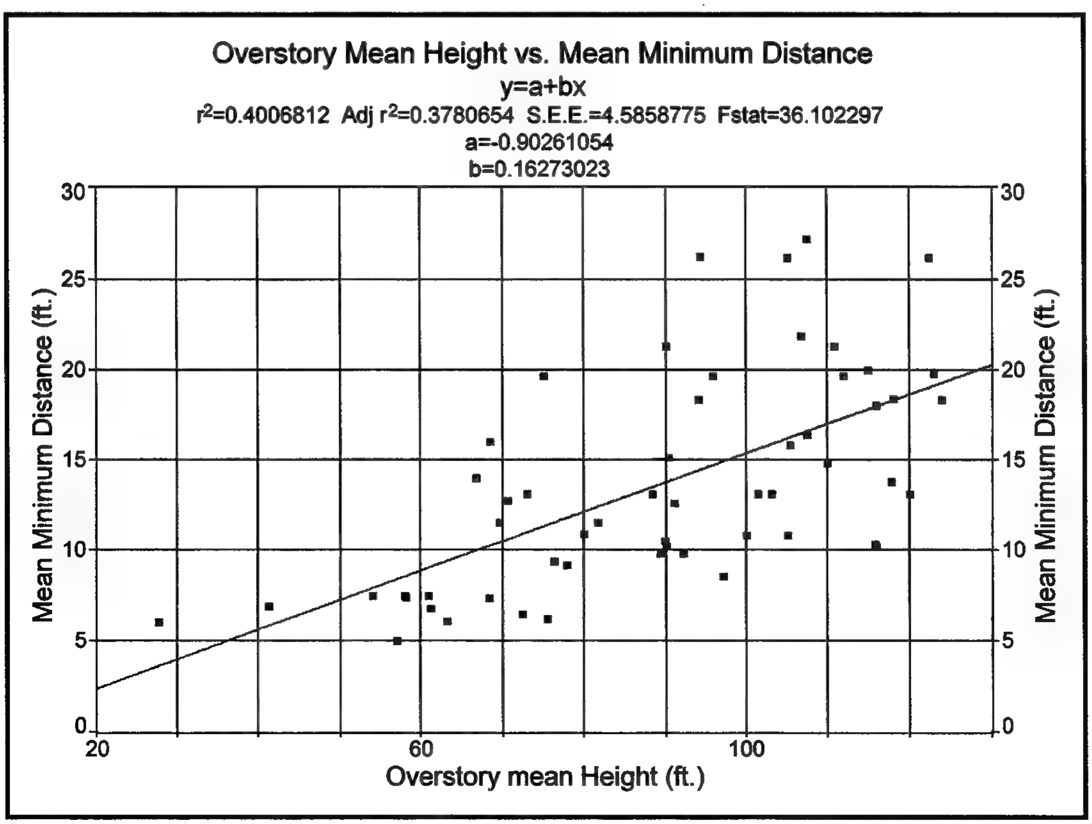

Figure 9. Overstory Mean Height vs. Mean Minimum Distance.

Overstory/Understory Relationships—Single Predictor (Independent) Variable

All of the measured and derived overstory and plot variables were used individually as independent variables for the regression. Table 5 contains the results of the regressions using single independent (predictor) variable to estimate understory stem density (stems per hectare). The r^2 values, even in the best cases, are relatively low (~0.50). Approximately one-half of the variability in the understory stem density can be explained by the overstory variables. Overstory mean crown diameter is the best predictor of understory stem density. The standard error of the estimate (value = 520) indicates that 95 percent of all understory stem density estimates should fall within ± 1040 understory stems. This translates into ±1 stem for every 103.5 sq ft (9.6 m^2). Figures 10 through 14 show plots of the first 5 of these regressions based on the coefficient of determination (r^2) and accompanying Standard Error of the Estimate (S.E.E.).

Figure 10 shows the capability of overstory mean crown diameter in estimating understory stem density. Older forests appear in the lower right-hand corner of the graph and younger forests in the upper left-hand corner of the graph.

Figure 11 shows the overstory stem density per hectare as a predictor of understory stem density. Older forests appear in the lower left portion of the graph and younger stands in the upper right corner

Figure 12 shows the overstory mean height as a predictor of understory stem density. Younger stands appear in the upper left-hand portion of the graph and older stands appear in the lower right hand corner.

Table 5. Regression Results of Understory Stem Density—Single Predictor Variable.

Predictor Variable	r^2	Adjusted r^2	Standard Error of the Estimate	Best-Fit Equation	Regression Coefficients		As predictor variable increases the number of understory stems
					a	b	
OS Mean Crown Diameter (ft)	0.56	0.54	520	y = a+b/x2	802.8	292273.0	Decreases
OS Stem Density -ha	0.54	0.52	534	y = a + bx2	1023.4	0.0026	Increases
OS Mean Height (ft)	0.51	0.49	547	y = a + bx0.5	-1832.6	30027	Decreases
OS Mean D.B.H. (in)	0.47	0.47	560	y = a + b/x2	839.5	81533.6	Decreases
Mean Min. Dist. (ft) of OS Stems	0.42	0.40	596	y = a + b/x	291.3	12779.7	Decreases
Variance of OS Crown	0.37	0.34	624	y = a + b/x0.5	727.0	4288.0	Decreases
Variance of OS Height	0.20	0.17	702	y = a + b/x2	1300.0	82683.0	Decreases
Slope of Plot (%)	0.22	0.19	730	y = a + be-x	1215.4	988.0	Decreases
Variance of OS D.B.H.	0.13	0.11	732	y = a + b/x0.5	943.2	1537.0	Decreases
Basal Area of the OS (in2)	0.02	0.0	776	y = a + bx3	1535.8	2.5E-08	Decreases

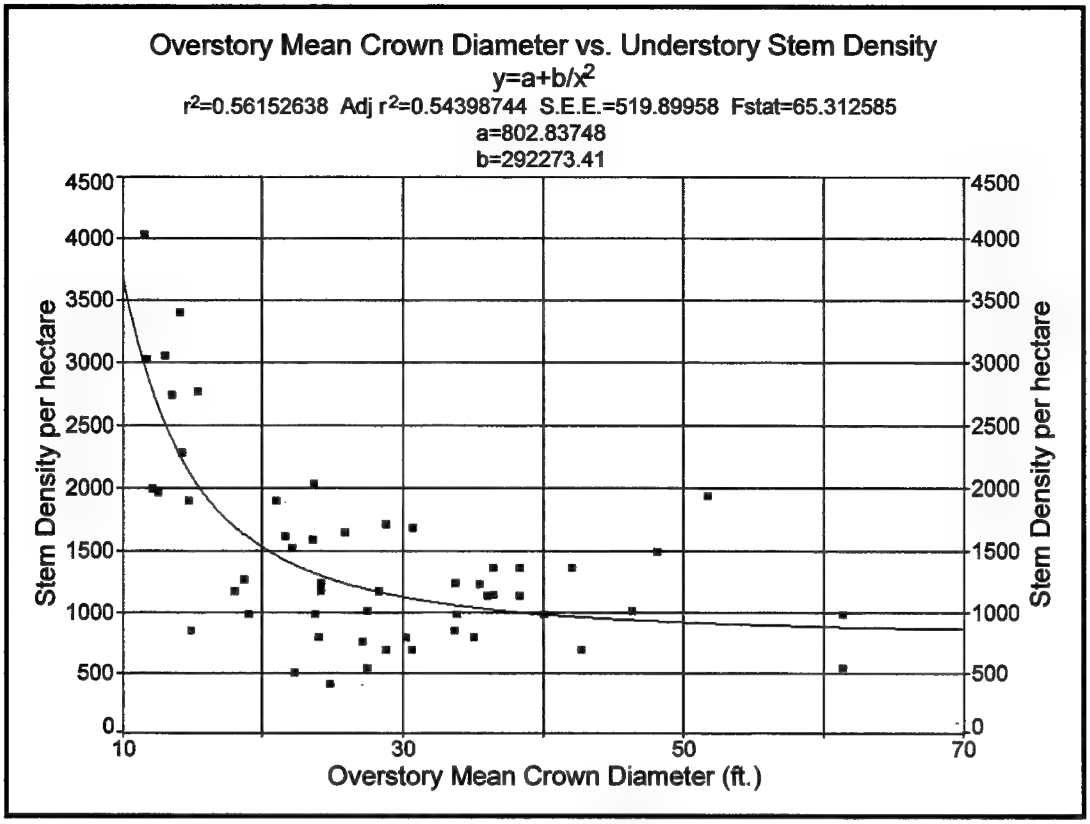

Figure 10. Overstory Mean Crown Diameter vs. Understory Stem Density.

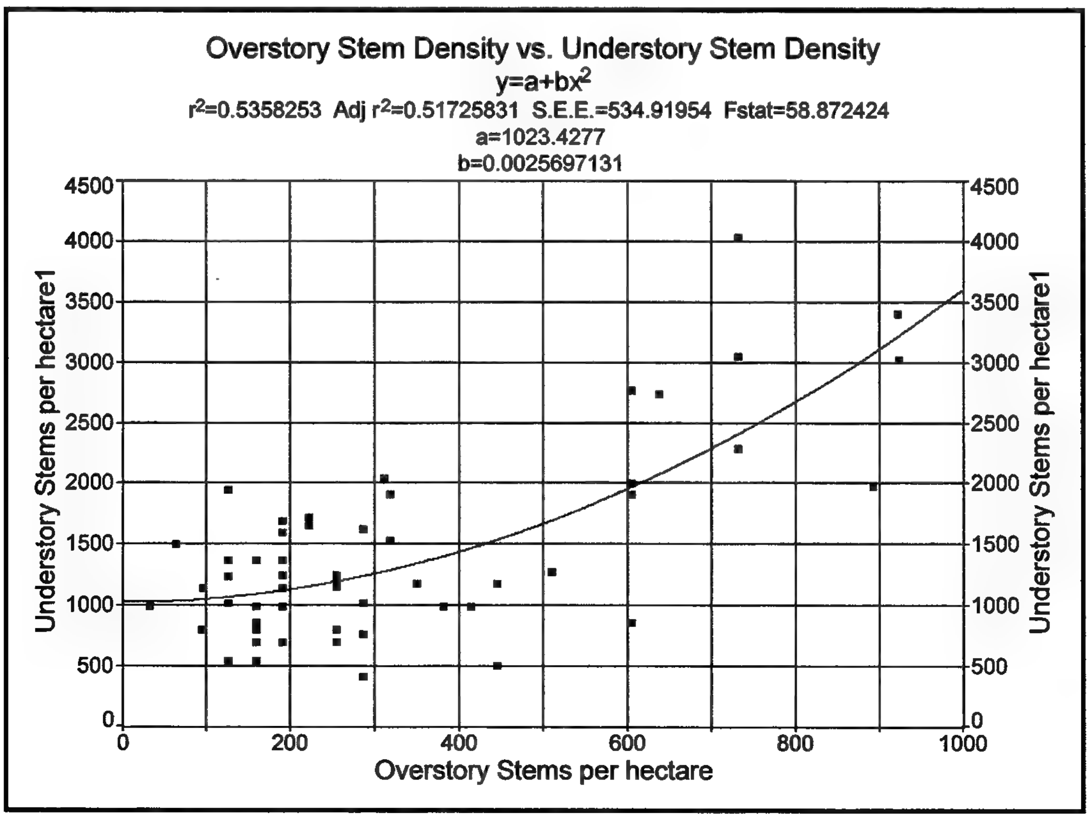

Figure 11. Overstory Stem Density vs. Understory Stem Density.

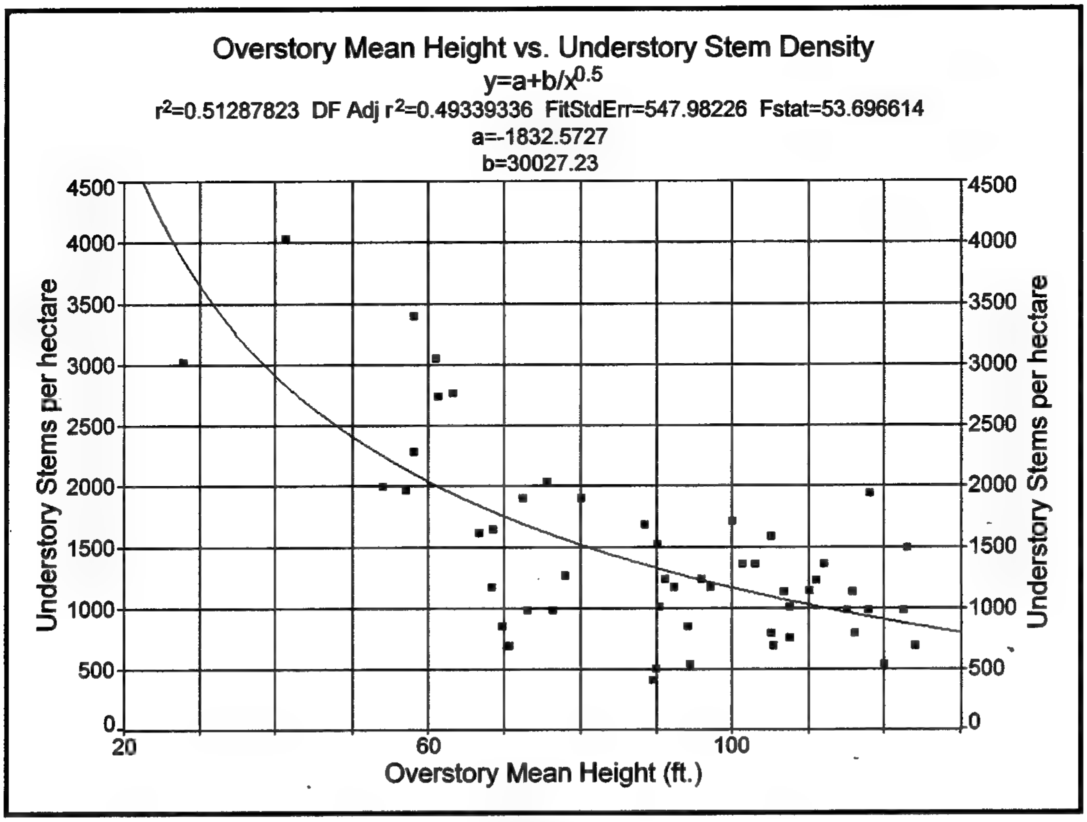

Figure 12. Overstory Mean Height vs. Understory Stem Density.

Figure 13 shows the overstory mean d.b.h. as a predictor of understory stem density. Younger stands appear in the upper left corner of the graph and older stands in the lower right portion of the graph.

Figure 14 shows the mean minimum distance of the overstory stems as a predictor of understory stem density. Younger, more dense stands appear in the upper left of the graph and older, less dense stands appear in the lower right.

Overstory/Understory Relationships—Multiple Regression Result

Multiple regression was then performed on the data set. The general purpose of multiple regression is to analyze the relationship between several predictor (independent) variables (overstory measures) and a dependent variable (understory stem density per hectare). Three different types of multiple regression were performed. *Standard multiple regression* enters all the predictor variables at once. *Forward stepwise multiple regression* adds or deletes individual independent variables until the best regression model is obtained. *Backward stepwise multiple regression* begins with all independent variables in the model and then removes one variable at a time until the best model is obtained.

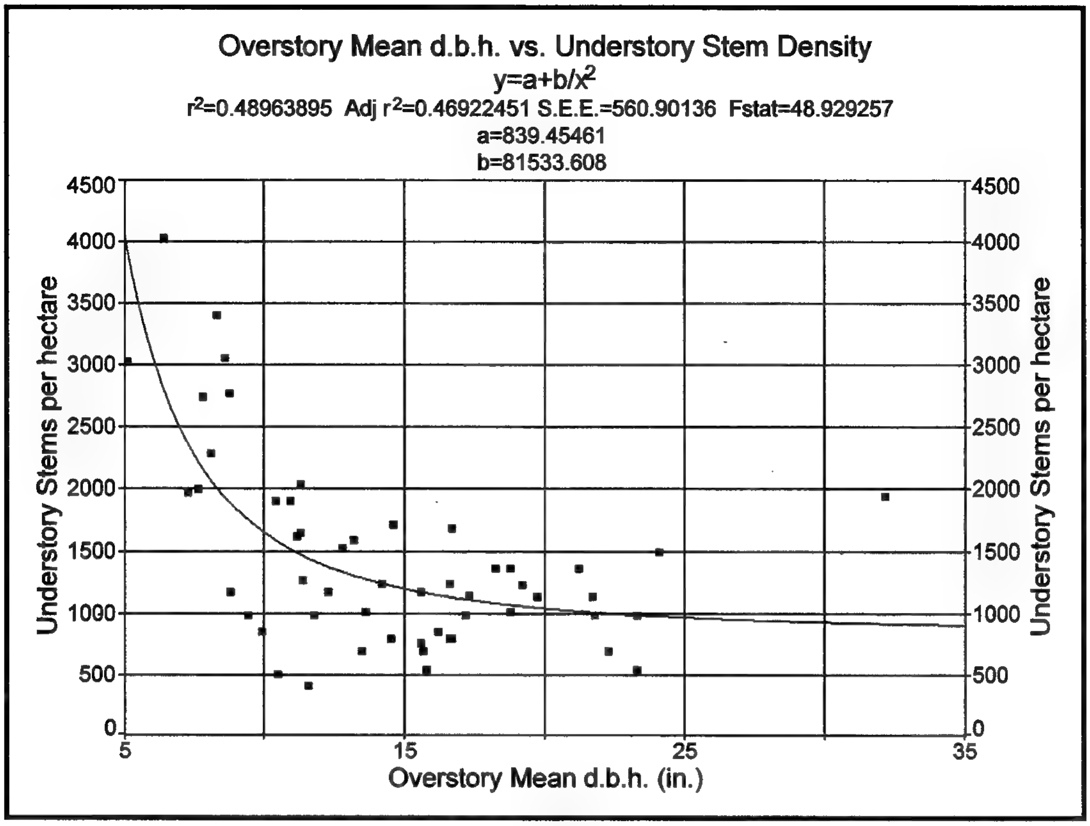

Figure 13. Overstory Mean d.b.h. vs. Understory Stem Density.

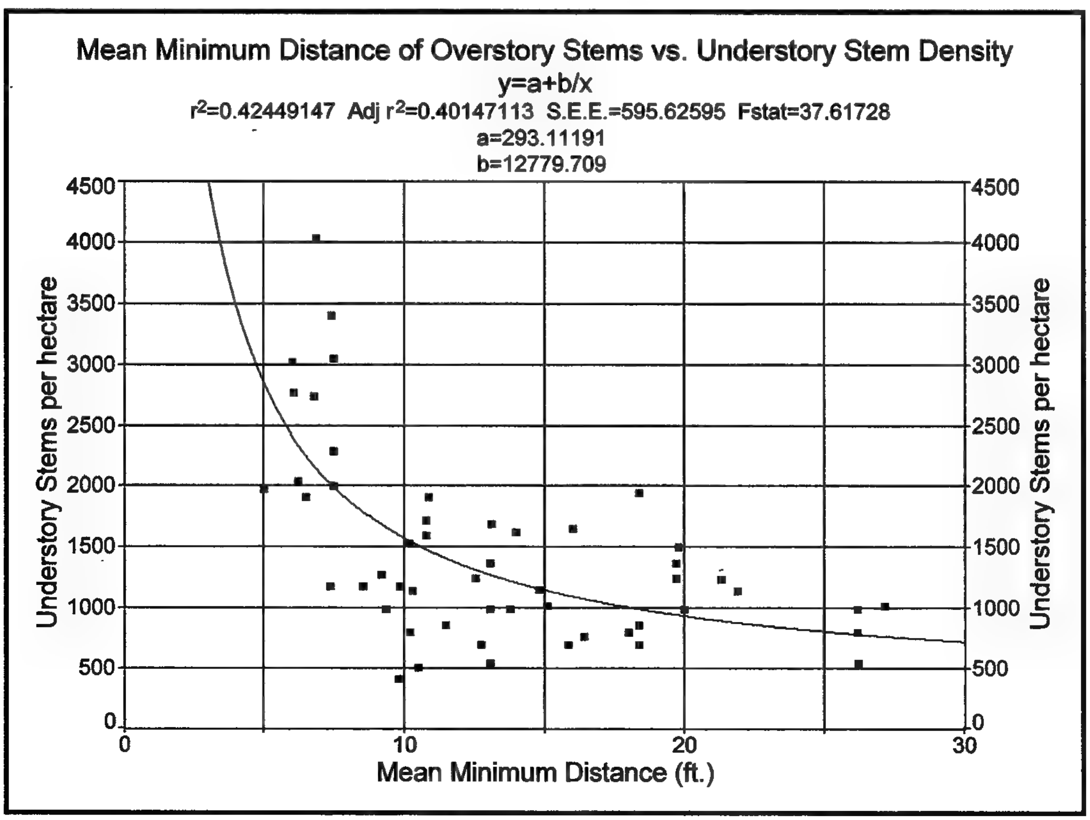

Figure 14. Mean Minimum Distance of Overstory Stems vs. Understory Stem Density.

Each of these different approaches in multiple regression was performed with both a y-intercept present and with the y-intercept set to zero. For variables to be accepted in the equation, their p-values had to be less than 0.05. This value, of course, is arbitrary, but small p-values help ensure that only statistically significant, nonzero coefficients are used in the model.

Figure 15 shows the results for the multiple regression for the 56 plots. Observed values of understory stem density appear on the y-axis and predicted values along the x-axis. The best-fit equation had no y-intercept and was:

Understory stem density per hectare = (2.997 x over stems per hectare) + (27.788 x overstory mean d.b.h.)

The multiple regression did not perform as well as when single predictor variables were used (see Figures 10 to 13). The r^2 value is omitted in Figure 15. Since there is no y-intercept, an r^2 value would represent the proportion of explained variability about the origin. This value cannot be compared directly to the r^2 value computed when the y-intercept is included.

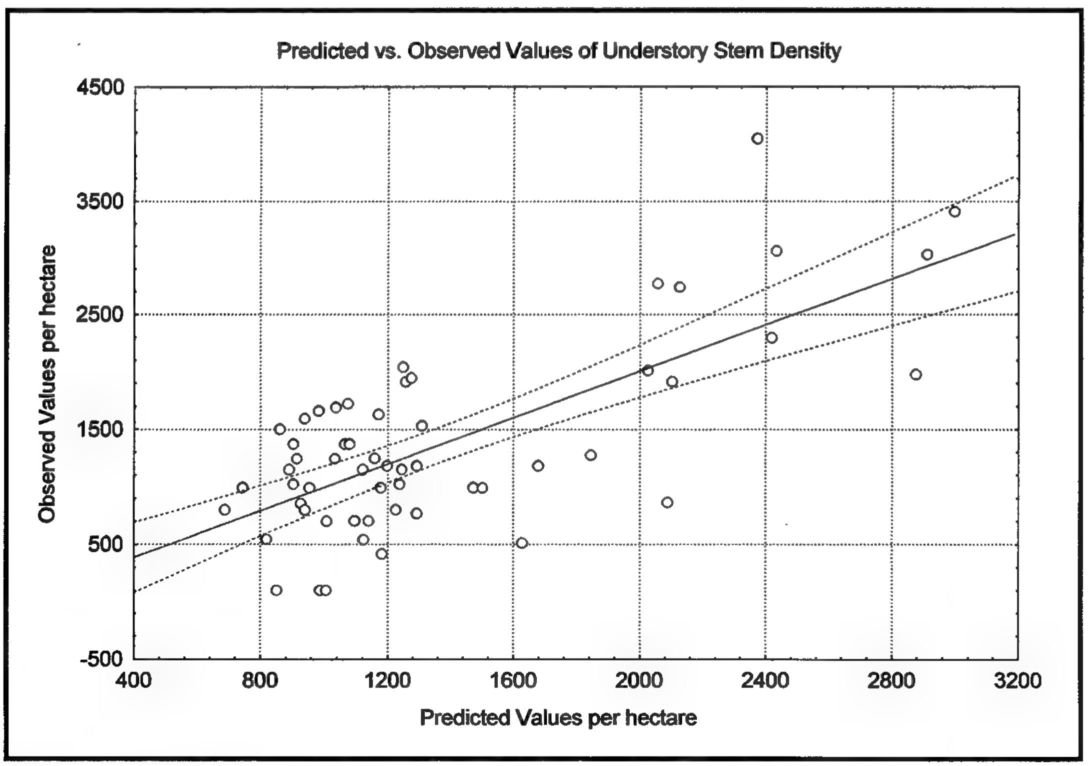

Figure 15. Predicted vs. Observed Values of Understory Stem Density.

6 Summary

Overstory and understory tree measurements were gathered at 56 locations in temperate, mid-latitude forest sites in Central Virginia. Plots were selected to provide samples from the full spectrum of forest structural types. Tree height, average crown diameter and diameter at breast height (d.b.h.) were measured for over 4300 overstory and understory stems on 10-m radius plots. Other plot information included: plot slope and aspect, drainage, soils, canopy closure, and types of vegetation that formed the herbaceous layer. This information was transferred into a statistical program, and simple and multiple regression were performed to find the best overstory variable(s) to use in predicting understory stem density.

Overstory mean crown diameter proved to be the best predictor of understory stem density. The S.E.E. for the simple regression of overstory mean crown diameter vs. understory stem density was 520 stems per hectare. This translates into 95 percent of all understory stem density estimations to be within +/- 1040 stems per hectare. The corresponding coefficient of determination (r^2), however, was 0.56. This indicates that only slightly above one-half of the variability in understory stem density could be explained by overstory mean crown diameter. Multiple regression proved to be a less accurate predictor (S.E.E. = 573.5 stems per hectare) than was simple regression.

7 Conclusions and Recommendations

There is a relationship between selected overstory parameters and understory stem density. When graphed, these relationships demonstrate rather structured patterns that are logical and explainable. The standard error of the estimate (S.E.E.), a measure of the dispersion of the observed values about the regression line, is somewhat excessive and the coefficient of determination (r^2) is less that desired. This may be due, in large part, to the fact that only 56 data points were available for analysis. The authors were unable to breakdown this data set further by species, ranges of height, crown, and d.b.h. or other salient characteristics. Once broken into smaller subsets, there were just too few data points with which to derive meaningful, stable equations. This was especially true when multiple regressions were performed (e.g., different sets of predictor variables were generated when forward, backward, and standard stepwise regression approaches were used). The researchers were forced to use the data set as a whole, mixing pure stands with mixed stands, coniferous with deciduous, etc.

It is also interesting to note that certain variables that have high correlations with vegetation species and forest density at other geographic sites have no apparent correlation in the Virginia piedmont. For example, *slope* and *aspect* have a noticeable relationship to species and density in most mountainous areas. However, these variables correlated quite poorly with the overstory and understory attributes gathered as part of this investigation.

Additional data need to be obtained to allow analysis by species, ranges of tree structural measurements, plot characteristics, etc. More work needs to be initiated focusing on the spatial variability of the understory. Furthermore, overstory and understory data need to be gathered at other geographic and climatic locations to provide an indication of the utility of any developed models outside of the midlatitude deciduous forest.

If the developed models are eventually deemed successful, then research needs to be conducted on the overall accuracy of the image analyst in measuring the required input variables.

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14. ABSTRACT

Current airborne imagery provides a fairly good mechanism for the measurement of such forest elements as tree crown diameter and tree height. The nature of the understory, however, can only be subjectively estimated by the analyst. Understory density and species composition can have an impact of such military activities as cross country mobility, cover and concealment, line-of-sight, and bivouac locations. This work involves the development of preliminary models to estimate understory stem densities through the use of measured overstory structural characteristics that can be derived by an image analyst. Over 4300 overstory and understory stems were measured at 56 sites at seven forested locations in central Virginia. Measured parameters included overstory and understory tree height, average crown diameter, diameter at breast height (d.b.h.), and species. Overstory tree locations within the plot (distance and azimuth) were computed and plot characteristics were gathered (slope, aspect, ground cover, drainage, soils, etc.). Preliminary equations were developed using simple and multiple regression to estimate understory stem density from these selected overstory stem characteristics.

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tree measurements, forest overstory, forest understory, forestry, statistical models, regression analysis

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